12p

18 Pgs

5 54387

NASA TN D-1610

NASA TN D-1610

N63-13187
Code 1

TECHNICAL NOTE

D-1610

SELF-ERECTING FLEXIBLE FOAM STRUCTURES FOR SPACE ANTENNAS

By Victor L. Vaughan, Jr., and Edward L. Hoffman

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON March 1963

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-1610

SELF-ERECTING FLEXIBLE FOAM STRUCTURES FOR SPACE ANTENNAS

By Victor L. Vaughan, Jr., and Edward L. Hoffman

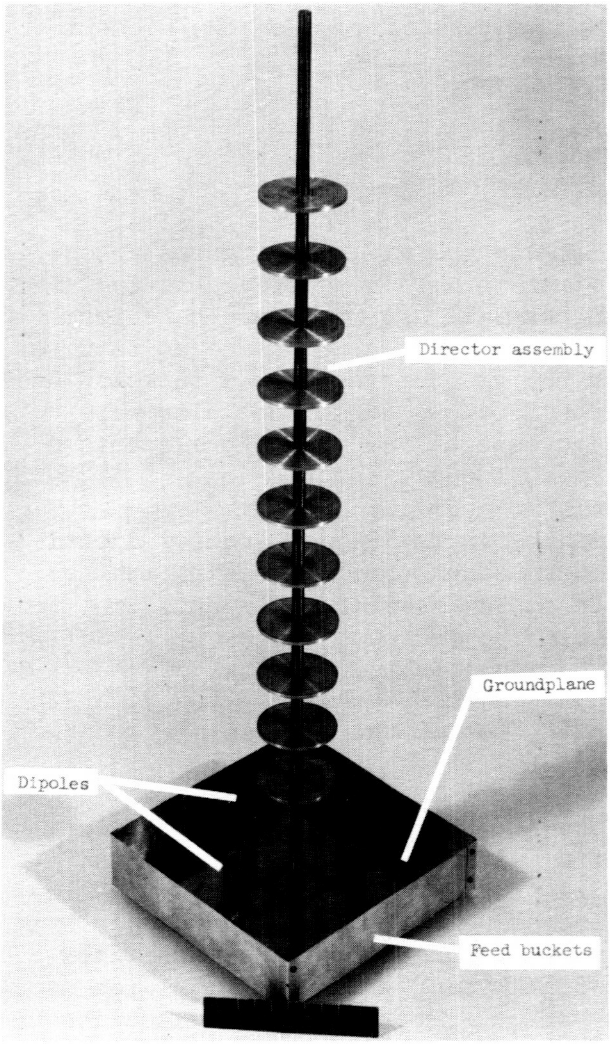
SUMMARY

The concept of using flexible foam for the erecting mechanism and supporting structure of erectable Yagi disk antenna elements for use in a space environment has been investigated. Tests were made to determine the recovery and stress-strain properties of the foams as they pertain to the erectable elements, and the effects of some vacuum and simulated solar radiation on these properties. Full-scale erectable Yagi disk antenna elements were investigated for packaging and erection ability, vibration damping in a vacuum, and temperature differential in a vacuum. The electrical performance characteristics of the erectable elements were compared with those of a standard element.

There were no significant detrimental effects of the simulated space environment on the recovery properties and resilience of the foam. The packaging, erection, damping, and temperature differential properties of the erectable elements were acceptable within the tolerances necessary for normal antenna performance. The electrical performance characteristics of the undisturbed erectable elements were essentially the same as those of a standard element.

INTRODUCTION

One of the basic problems in the design of erectable structures for space vehicles is to meet packaging requirements during the vehicle launch phase without unduly complicating the erection technique. One simple technique for erection is using flexible foam which can be compressed for packaging and which when released is inherently self-erecting. This same material may also be used for the supporting structure of vehicles or components. In this connection, the concept of using flexible foam for the erecting mechanism and supporting structure of erectable Yagi disk antenna elements for use in a space environment has been investigated. A description of the antenna element used as the basic configuration for the erectable elements is given in reference 1, and a photograph of the element used as a standard element is shown in figure 1. In the present investigation, the director assembly of the element, which consists of a rod with 11 equally spaced disks, was made erectable by replacing the rod with flexible foam.



L-61-5318

Figure 1.- Yagi disk antenna (standard element).

Since the erectable elements were dependent on the flexible foam for mechanical performance and structural integrity in a space environment, investigations were made to determine the recovery and stress-strain properties of the foams and the effects of some vacuum and simulated solar radiation on these properties. Investigations were then made to determine the packaging and erection ability of the erectable elements and how the erection compared with the recovery properties of the flexible foams. The erectable elements were also investigated for vibration damping and the effects of temperature differential in a vacuum to determine their ability to remain within the allowable tolerances necessary for proper electrical performance. The electrical performance characteristics of two of the erectable elements were measured (ref. 1) and compared with those of a standard element.

YAGI DISK ANTENNA ELEMENTS

The Yagi disk antenna element was chosen as the basic configuration for the erectable elements because of its broadband properties. When these properties are interpreted in terms of physical dimensions, they allow large physical tolerances on the structure when used in narrow band application. Since lightweight flexible structures are required for erectable antennas, the physical tolerances of the Yagi disk antennas looked very favorable. A study and evaluation of the Yagi disk antenna elements and arrays of these elements are presented in reference 1.

The elements consisted of two basic parts. (See fig. 1.) One was the dipole-groundplane unit which incorporated the groundplane, feed buckets, and dipoles. The second part was the director assembly which consisted of 11 directors (disks) equally spaced on a rod. The least critical of the structural tolerances necessary for proper electrical performance of the elements were disk spacing and deflections of the director assemblies. For instance, variations up to ±25 percent in disk spacing could occur without serious degradation of the element gain, and deflections of ±1 inch (measured at the tip of the element) had no significant effect on the antenna patterns; however, deflections as large as ±2 inches caused the beam to tilt slightly and increased the sidelobe level. Since both of these tolerances were associated with the director assembly, this part of the element was selected as the most amenable for the erectable structure.

DESCRIPTION OF ERECTABLE ELEMENTS

Sketches and pictures of the erectable elements are given in figures 2 to 4. In general, the director assemblies of these elements were made erectable by replacing the rod in the standard element with polyether flexible urethane foam which also acted as spacers for the directors. The dipole-groundplane units were made of formica printed-circuit board on which the groundplanes, feed buckets, and dipoles were etched. For this investigation the dipole-groundplane units were considered only as housing units for the director assemblies when the elements were packaged.

There were four erectable elements used in the investigation and for identification purposes they are designated as follows: (the number preceding the name denotes the density in pounds per cubic foot of the flexible foam used in the director assembly).

(1) 1.7 cylindrical element

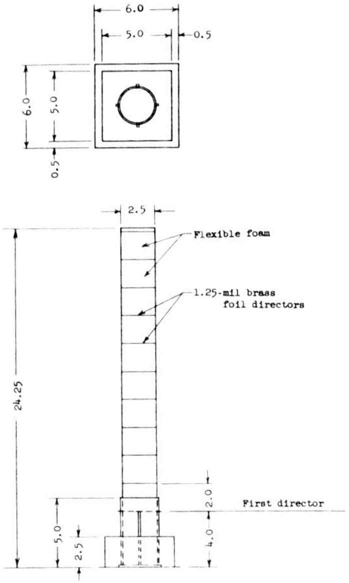
(2) 1.0 cylindrical element

(3) 1.7 pyramidal element

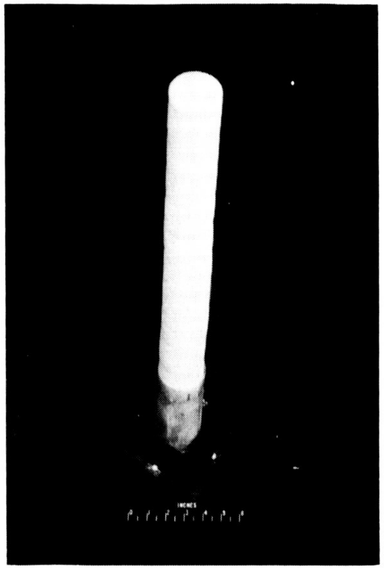
(4) 1.0 pyramidal element

The only difference in the two cylindrical elements was the density of the flexible foam. A sketch of the elements is given in figure 2 along with pictures of the 1.7 cylindrical element. The directors in the elements, with the exception of the first (directors nearest the groundplanes), were made of 1.25-mil perforated brass foil. The first directors were made of formica printed-circuit board and had four tabs which fitted into slots in the fiber glass and plastic canisters mounted in the center of the dipole-groundplane units. These slots acted as guides and stops to position accurately the first directors above the groundplanes when the elements were erected. Flexible foam, between the groundplanes and first directors, remained under slight compression after erection to hold these directors in place. The canisters housed the director assemblies when packaged. (See fig. 2(c).) The dipole-groundplane units of the cylindrical elements did not have feed buckets since they were unnecessary in the structural tests, but they were added for the range test reported in reference 1.

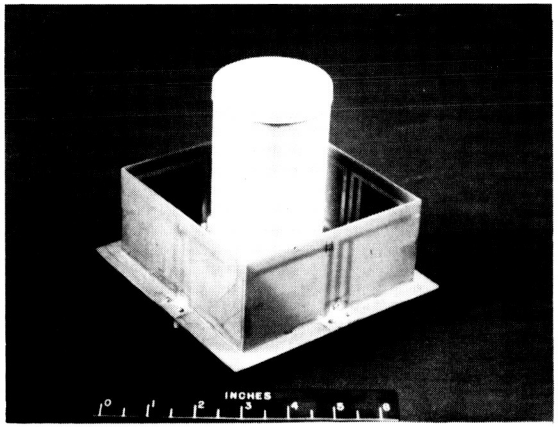
It was apparent that the director assemblies of the cylindrical elements were very limber and that forces such as those encountered during changes in orientation of a space vehicle would result in deflections that might exceed the allowable tolerances. Two new elements were built with increased stiffness by using larger foam spacers in the director assemblies. The foam in these elements was shaped to form frustums of pyramids.



(a) 1.0 and 1.7 cylindrical elements (densities 1.0 lb/cu ft and 1.7 lb/cu ft).

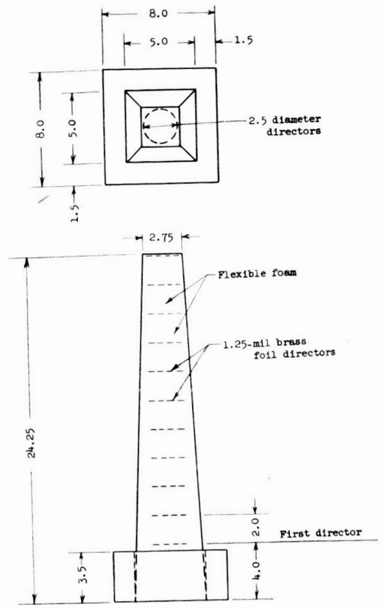


(b) 1.7 cylindrical element (erected). L-61-4838

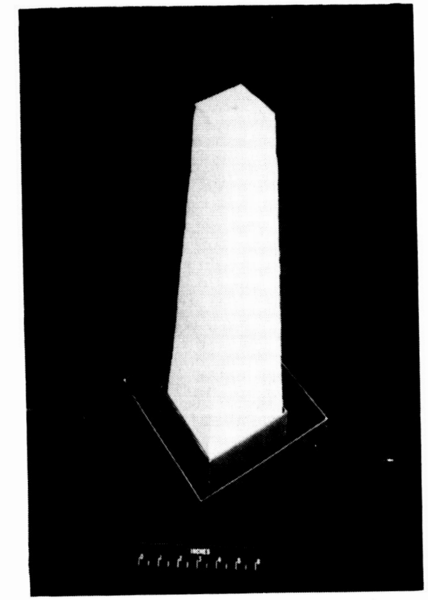


(c) 1.7 cylindrical element (packaged). L-61-4837

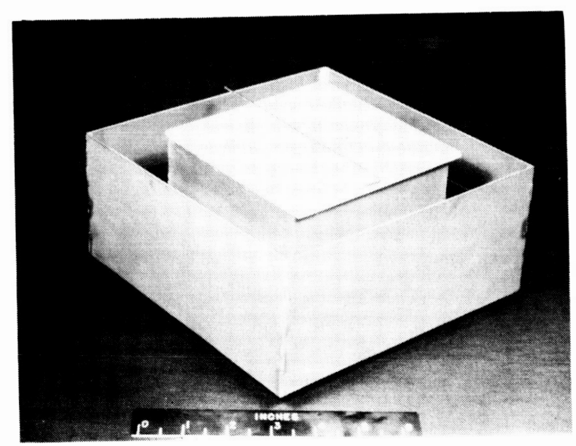
Figure 2.- Sketch and pictures of the cylindrical elements without feed buckets. (Dimensions are full scale in inches.)



(a) 1.7 pyramidal element.

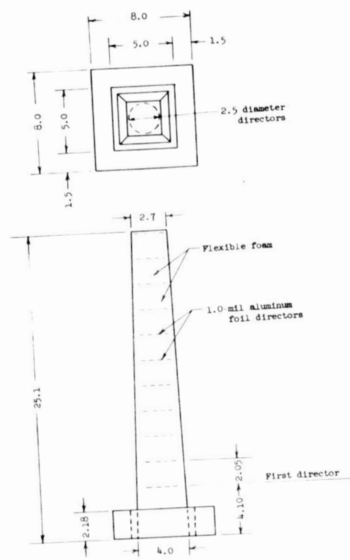


(b) 1.7 pyramidal element (erected). L-61-4833

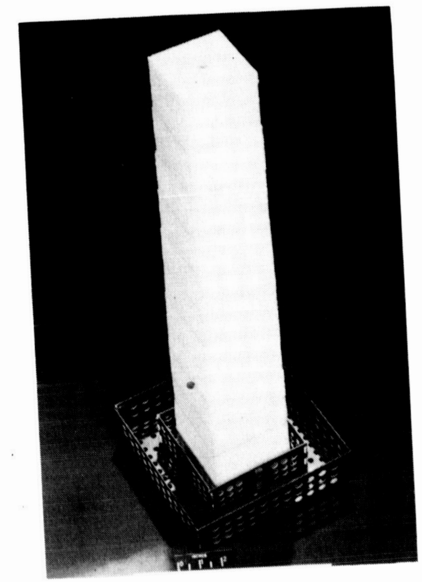


(c) 1.7 pyramidal element (packaged). L-61-4836

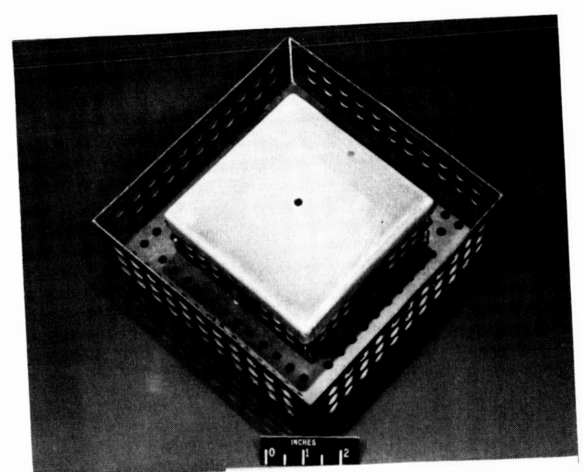
Figure 3.- Sketch and pictures of the 1.7 pyramidal element. (Dimensions are full scale in inches.)



(a) 1.0 pyramidal element.



(b) 1.0 pyramidal element (erected). L-61-7882



(c) 1.0 pyramidal element (packaged). L-61-7883

Figure 4.- Sketch and pictures of the 1.0 pyramidal element. (Dimensions are full scale in inches.)

The 1.7 pyramidal element is shown in figure 3. The directors in this element were made of 1.25-mil perforated brass foil and no special effort was made to position the first director accurately. The dipole box of the dipole-groundplane unit was 3.5 inches high to facilitate packaging and the feed buckets were of an equal height to retain symmetry.

The 1.0 pyramidal element is shown in figure 4. The directors in this element were made of 1.0-mil aluminum foil. The dipole-groundplane unit was 2.18 inches high to accommodate the dipoles and feed buckets which, in this case, corresponded to the height of the element when packaged.

FLEXIBLE FOAM

The polyether flexible urethane foams used in this investigation were of open-cell construction and white in appearance. They had densities of 1.7 and 1.0 pounds per cubic foot and all the test samples and director spacers of a given density were cut from a single block of foam. Both foams had an effective grain in their cell structure which was apparently a result of the foaming process. This effective grain allowed the foam to compress properly only in a direction perpendicular to the grain. Compression in any other direction caused a transverse deflection or folding of the foam. An example of the transverse deflection is shown in figure 5 which is a picture of a cylindrical foam spacer

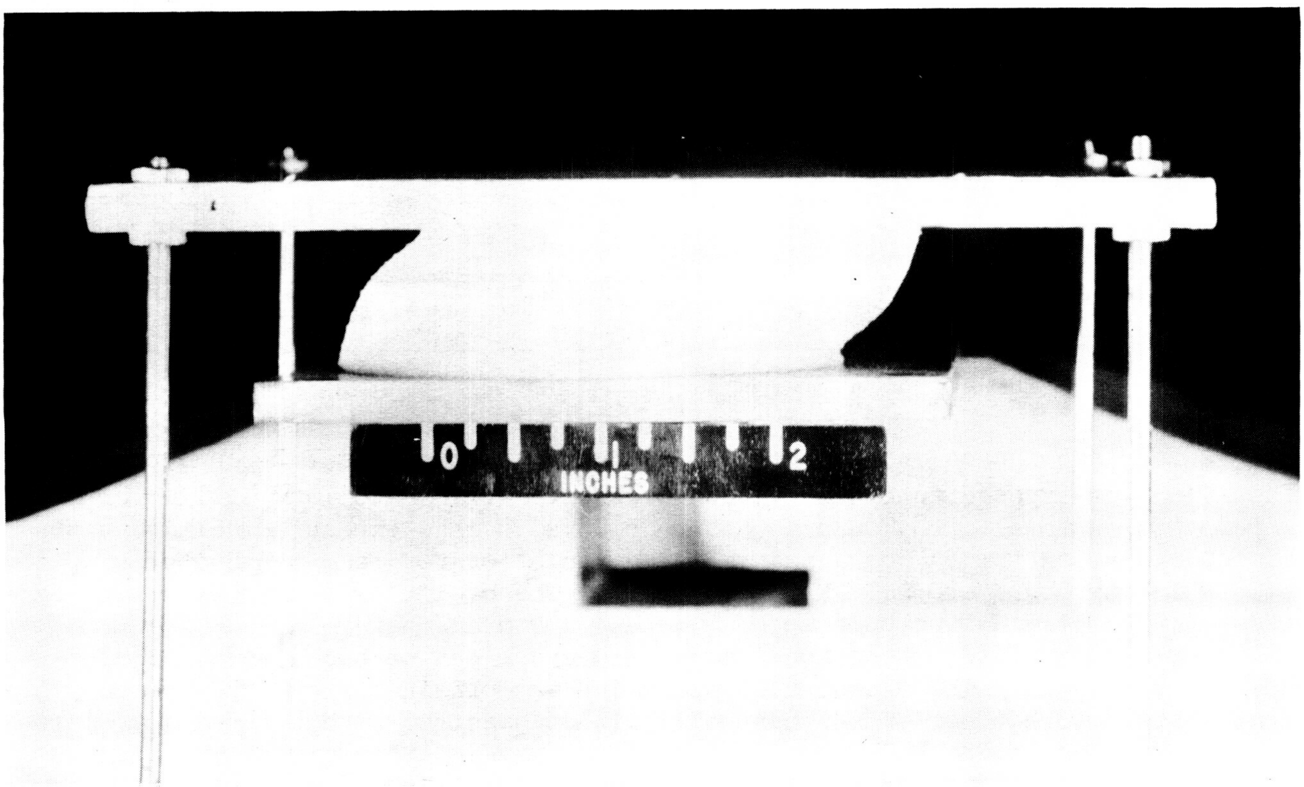


Figure 5.- Transverse deflection of foam sample subjected to a floating load. L-61-4843

subjected to a floating load acting diagonally across the grain. The direction of the grain was not necessarily consistent throughout a single block of foam; therefore, in cutting samples and director spacers from different parts of a block, it was necessary to cut them oversize, determine the grain direction, and recut them so that the grain was properly oriented with respect to the loading or compression direction.

APPARATUS AND PROCEDURE

Simulated Space Environment

The simulated space environment to which samples of the 1.0- and 1.7-pound-per-cubic-foot foams were exposed are given in table I. The exposures were made in a bell-jar vacuum chamber (18 inches in diameter and 30 inches high).

TABLE I.- VACUUM AND SOLAR RADIATION EXPOSURE OF POLYETHER FLEXIBLE URETHANE FOAM

Vacuum pressure (average), mm Hg	Radiation	Foam temperature, °F	Exposure time (total), hr	Remarks
Foam density, 1.7 lb/cu ft (a)				
2.5×10^{-2}	-----------------	77	570	No change
5.0×10^{-6}	-----------------	77	129	No change
1.0×10^{-5}	Ultraviolet 3,650 to 3,663A	90	53	Slight discoloration
2.0×10^{-4}	Infrared	150	25	No change
2.0×10^{-4}	Infrared	200	70	Weight loss (0.3 percent)
Foam density, 1.0 lb/cu ft (a)				
1.0×10^{-5}	Ultraviolet 3,650 to 3,663A	140	50	No change

[a]Specimen size = 3 in. diameter × 2 in. high.

A sample 3 inches in diameter and 2 inches thick of the 1.7-pound-per-cubic-foot foam was exposed to cyclic vacuum pressures of 10^{-2} to 10^{-6} millimeters of mercury for a total of 847 hours (about 35 days). This exposure included ultraviolet radiation for 53 hours and infrared radiation for foam temperatures up to 150° F for 25 hours and 200° F for 70 hours. The cyclic exposure resulted from the vacuum-system diffusion pump and radiation sources being turned off during the time the system could not be monitored. The cycle can be based on a normal 5-day 40-hour work week. The ultraviolet radiation was obtained from a BH6 mercury arc lamp which covered most of the near ultraviolet spectrum with the primary ultraviolet emission in the 3,650 to 3,663 angstrom wavelength region. The lamp was mounted externally and radiated through a quartz port in the base plate of the bell jar with about 10-percent loss. The sample was placed 18 inches from the lamp. The infrared heat was obtained from a 500-watt quartz heater mounted above a Mycalex reflector and about 6 inches from the foam sample. The foam temperature was measured by a copper-constantan thermocouple imbedded in the foam about 1/8 inch from the surface of the foam.

A sample 3 inches in diameter and 2 inches thick of the 1.0-pound-per-cubic-foot foam was exposed to a continuous vacuum pressure of 1×10^{-5} millimeters of mercury and ultraviolet radiation from the BH6 mercury arc lamp for 50 hours. The sample was placed 15 inches from the lamp.

Foam Recovery Test

The recovery properties of foam samples 3 inches in diameter and 2 inches thick and with a density of 1.7 pounds per cubic foot were determined at atmospheric pressure after being compressed to a ratio of about 8 to 1 for 20 hours. The recovery properties of foam samples 4 inches square and 4 inches thick with a density of 1.0 pound per cubic foot were determined at atmospheric pressure and at a pressure of 1×10^{-5} millimeters of mercury after being compressed to a ratio of about 12 to 1 for 20 hours. For the atmospheric tests, the samples were compressed with dead weights and recovery was measured mechanically at varying time intervals after the weights were removed. For the test in the vacuum, the foam was compressed by a motor-driven plunger. When measuring the recovery, the plunger was backed off from the foam as a thin metal disk on the surface of the foam shorted two contacts in the base of the plunger and completed the electrical circuit to the drive motor. The amount of plunger travel was obtained with a Brown recorder through the use of a calibrated variable resistor driven directly off the plunger shaft. For the first 3 minutes of recovery, the foam was restricted by the plunger since the system could not respond as fast as the foam recovered.

Foam Stress-Strain Test

The stress-strain characteristics of the 1.7- and 1.0-pound-per-cubic-foot foams were determined at atmospheric pressure by subjecting foam samples 3 inches in diameter and 2 inches thick to compression loads with dead weights. The loads were applied progressively without unloading until a strain of about 75 percent was reached and then the loads were removed in the same manner. One of the characteristics of flexible foam is that the strain under load is time dependent. Figure 6 shows the variation of strain with time for a foam sample subjected to a constant load and with the load removed. From these data, it is apparent that useful strain data can only be determined after sufficient time has elapsed so that strain is no longer changing rapidly with time. Therefore, the strain of the foam was measured mechanically 5 minutes after each load change.

Vibration Damping Test

Vibration damping of the 1.0 cylindrical element and the 1.7 pyramidal element were determined in the vacuum chamber described previously at a pressure of

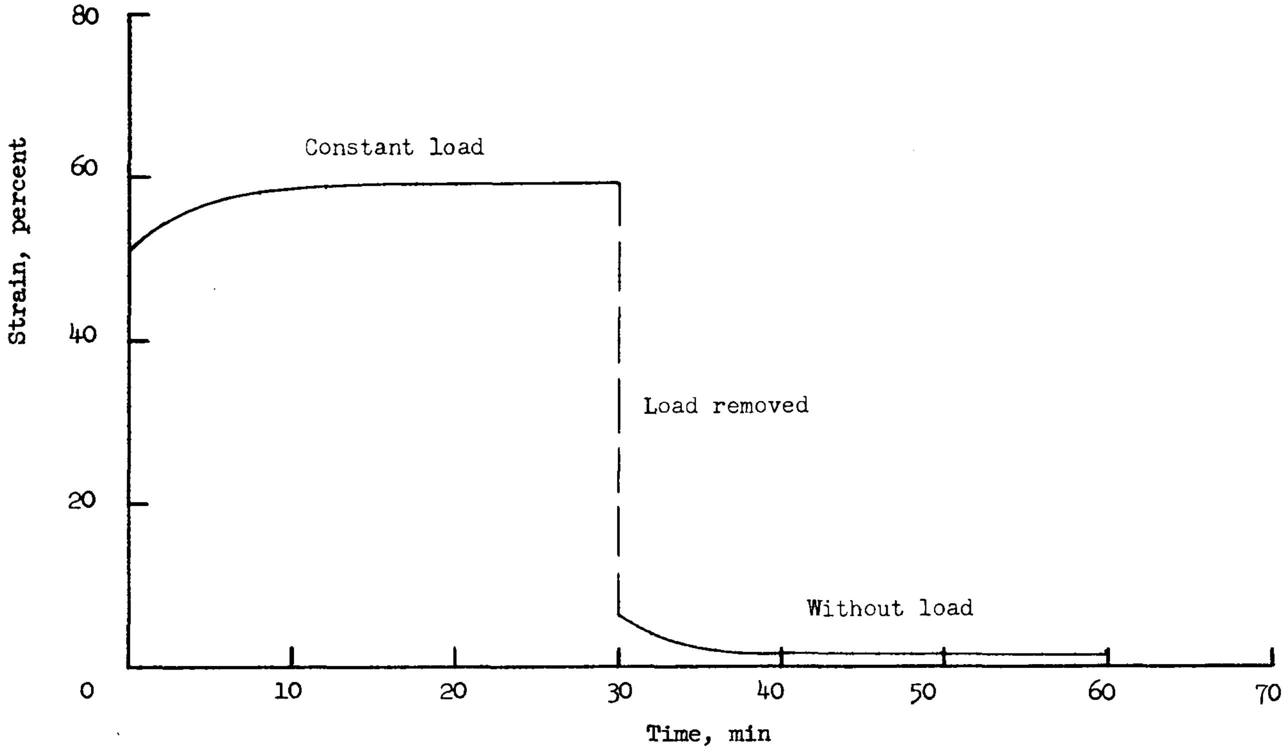


Figure 6.- Time variation of strain in flexible foam. Foam density, 1.7 pounds per cubic foot.

5×10^{-6} millimeters of mercury. The elements were tested when hanging vertically to minimize the effect of gravity and were plucked so they vibrated freely. The vibrations were recorded with the use of an optical system in which collimated light was directed on small prisms attached to the ends of the elements. The light was reflected by the prisms through a thin slot in a film drum and onto the enclosed film. The film was moving past the slot at a rate of 1/2 inch per second.

Temperature Differential Test

The effect of temperature differential on the 1.7 pyramidal element was determined in a steel vacuum chamber 2.5 feet in diameter and 5 feet long at a pressure of 2×10^{-5} millimeters of mercury. The element was suspended from the top of the chamber so that the director assembly was in a vertical position. One side of the director assembly was cooled by means of a liquid nitrogen reservoir and the opposite side was heated with a 2,500-watt quartz infrared lamp mounted in front of a reflector. Copper-constantan thermocouples were imbedded 1/8 inch in the foam and a continuous record of the temperatures was obtained with a Brown recorder. The deflections due to the temperature differential were obtained from pictures of the director assembly taken through a port in the side of the vacuum chamber.

RESULTS AND DISCUSSION

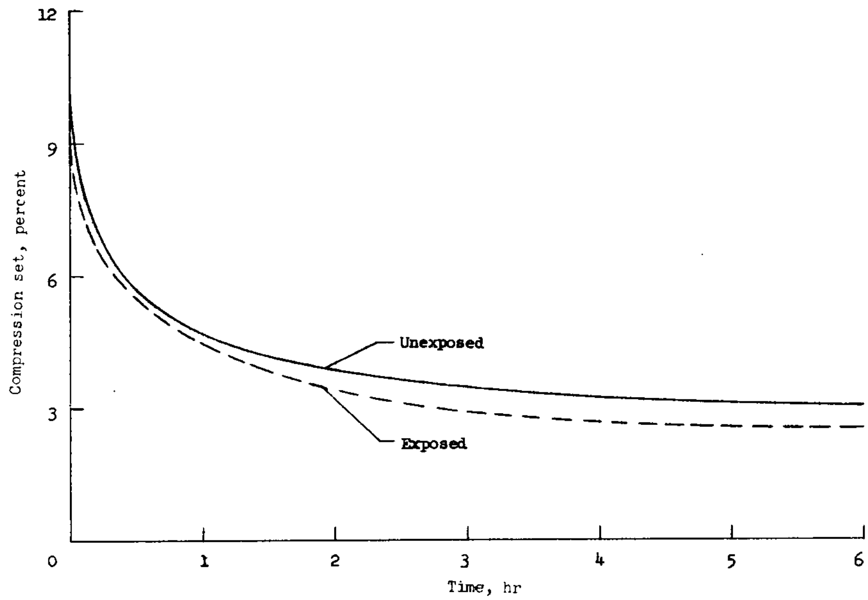
Flexible Foam

Environmental exposure.- The vacuum and simulated solar radiation to which the foam samples were exposed and some of the results of these exposures on the foams are presented in table I. The only visible effect of the environmental exposure on the 2-inch-thick 1.7-pound-per-cubic-foot foam sample was a slight discoloration of the foam due to the ultraviolet radiation. The loss in weight of the foam sample was only 0.3 percent and occurred while at foam temperatures of 200° F during the infrared radiation exposure. The effects of the environmental exposure on the recovery and stress-strain properties of the 1.7-pound-per-cubic-foot foam are given in subsequent sections of this report.

There was no weight change or discoloration of the 1.0-pound-per-cubic-foot foam sample due to the vacuum and ultraviolet radiation to which it was exposed.

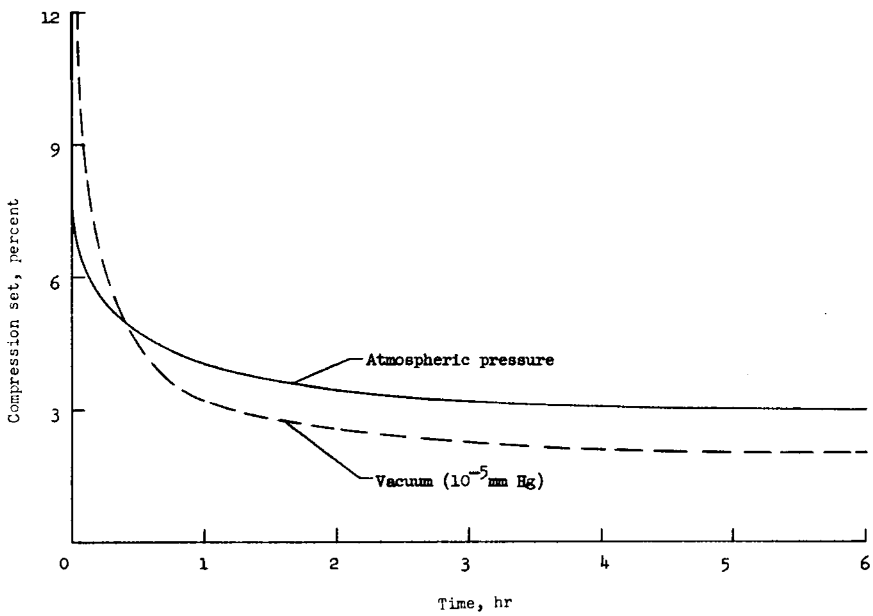
Recovery properties.- The recovery properties of the foams are expressed as compression set in percent of original thickness and plotted against recovery time in hours in figure 7. The data for the 1.7-pound-per-cubic-foot foam (fig. 7(a)) are presented as a comparison of the recovery properties before and after the environmental exposure. The data for the 1.0-pound-per-cubic-foot foam (fig. 7(b)) are presented as a comparison of recovery properties at atmospheric pressure and in a vacuum (1×10^{-5} mm Hg). In general, these data show the foams recovered almost immediately to within 10 percent of their original thickness after constant deflections for 20 hours, and continued to recover for about 6 hours at which time they retain compression sets of about 2 to 3 percent. The 1.7-pound-per-cubic-foot foam showed slightly better recovery properties after the environmental exposure. Because the recovery of the 1.0-pound-per-cubic-foot foam in a vacuum was restricted by the measuring system for the first 3 minutes, the foam did not have the initial spring back after release as did the foam at atmospheric pressure when the weights were suddenly removed. Even with this restriction the foam recovered to a 3-percent compression set after about 1 hour as compared with about 5 hours at atmospheric pressure.

Stress-strain properties.- The loading and unloading stress-strain properties of the 1.7-pound-per-cubic-foot foam, before and after the environmental exposure, and of the unexposed 1.0-pound-per-cubic-foot foam are shown in figure 8. The general shape of the curves shows that, after an initial strain of about 8 percent of the original thickness, stress increased very little with strains up to 50 percent. With further increase in strain, the stress increased rapidly. It may be noted that the lighter foam required less than half the stress for a strain of about 75 percent as that required by the denser foam. The compression resilience of the foam is defined as the area under the unloading curve as a percent of the area under the loading curve. The resilience of the denser foam was 52 percent before and after the environmental exposure and thus indicates that there was no effect of the exposure on the recovery rate of the foam. The difference in the two curves is within the scatter range that can be expected from two samples cut from the same block of foam. The resilience of the lighter foam was 59 percent and thus the recovery rate of the lighter foam was slightly higher than that of the denser foam.



(a) Effect of the environmental exposure. Foam density, 1.7 pounds per cubic foot.

Figure 7.- Recovery properties of the flexible foams.



(b) Effect of vacuum on recovery properties. Foam density, 1.0 pound per cubic foot.

Figure 7.- Concluded.

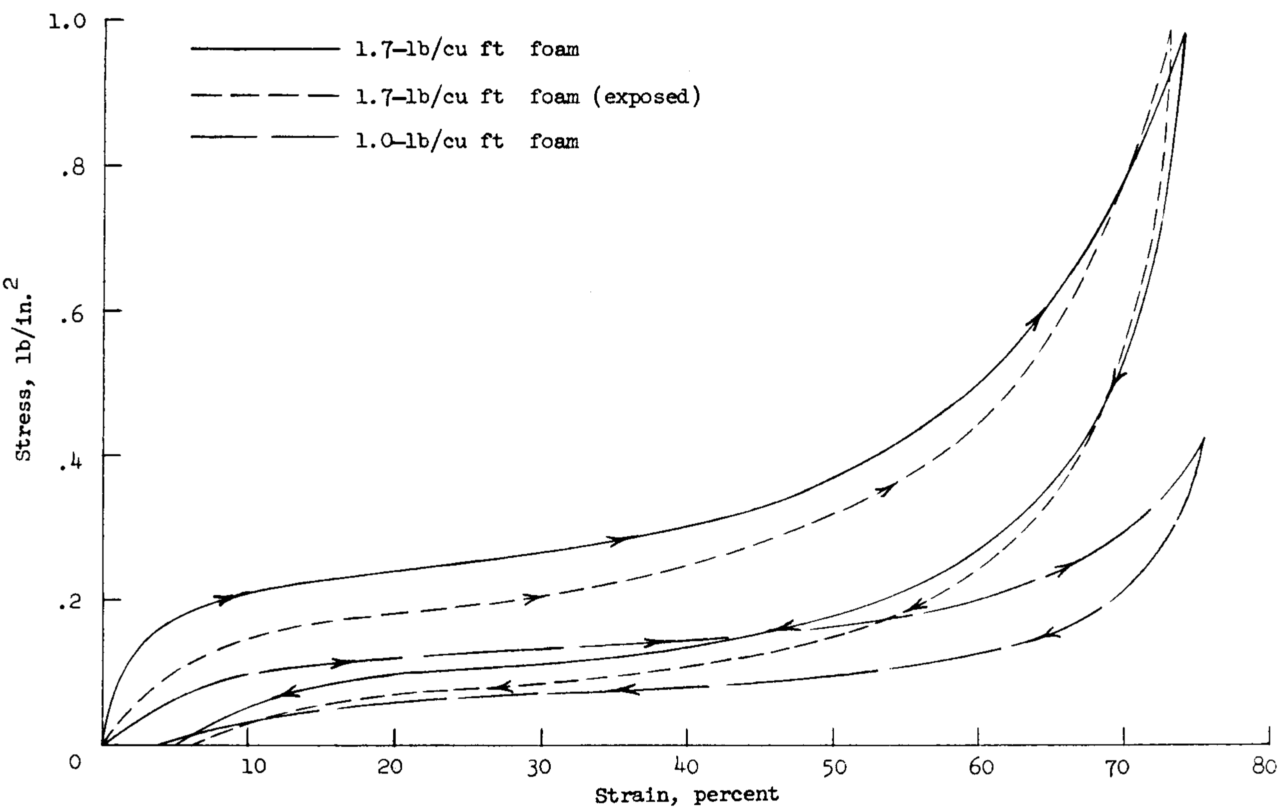


Figure 8.- Stress-strain properties of the 1.7-pound-per-cubic-foot flexible foam before and after the environmental exposure and the unexposed 1.0-pound-per-cubic-foot flexible foam.

Erectable Elements

Packaging and erection.- The package ratios of the two cylindrical elements were fixed at about 4.8 to 1 by the length of the canisters into which the director assemblies were packaged. The 1.7-pound-per-cubic-foot foam could normally be packaged to a ratio of about 8 to 1 with the effective grain properly oriented. The grain of the foam was not properly oriented in the 1.7 pyramidal element (fig. 3), and a package ratio of only 7 to 1 could be obtained because of the transverse deflection and folding of the foam. The effective grain of the foam was properly oriented in the 1.0 pyramidal element (fig. 4) and the element was packaged to a ratio of about 12 to 1.

All elements, regardless of the density of the foam in the director assemblies, erected to within 10 percent of their original lengths immediately upon release after being packaged for 20 hours and retained compression sets of about 3 percent after 6 hours recovery time. The recovery of the elements followed the same curves as the foam samples at atmospheric pressure given in figure 7. The addition of the directors and the necessary bonding agents in the director assemblies had little effect on the recovery properties of the foams. The erection of the elements is well within the allowable tolerance of ±25 percent given for this type of antenna. (See ref. 1.)

Damping properties.- The vibration damping of the 1.0 cylindrical element and the 1.7 pyramidal element was determined while vibrating freely in a vacuum. Since the foam densities are different in these elements, the data are not directly comparable but are presented to give a general idea of the frequencies and damping times involved. The 1.0 cylindrical element vibrated at a frequency of 1.3 cycles per second and damped to half-amplitude in 3.2 seconds. The 1.7 pyramidal element vibrated at a frequency of 3.4 cycles per second and damped to half-amplitude in 0.9 second. If the forces tending to deflect the elements were continually repeated at very short intervals, the stiffer pyramidal element would be the more desirable. Also for a given disturbing force, the amplitude of vibration would be considerably less for the pyramidal element.

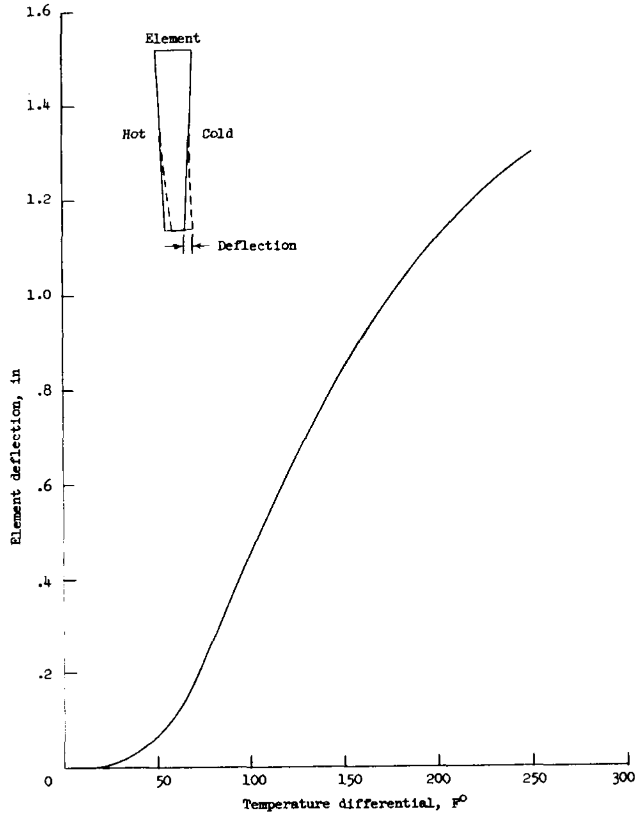


Figure 9.- Effect of temperature differential on the 1.7 pyramidal element at a pressure of 2×10^{-5} millimeters of mercury.

Temperature differential.- The effects of temperature differentials on the 1.7 pyramidal element are given in figure 9. The element deflection represents the tip deflections of the director assembly. The maximum deflection obtained was 1.3 inches at a temperature differential of 250° F. From the deflection tolerances previously stated, it is apparent that somewhat greater differentials can occur without serious degradation to the electrical performance of the antenna.

Comparison With Standard Element

Radiation patterns of two of the undisturbed erectable elements were measured and the results are reported in reference 1. A comparison of the beam widths of the erectable elements with those of a standard element over a range of frequencies from 1,200 to 1,750 megacycles is given in figure 10. These data indicate that the electrical performance of the erectable elements is essentially the same as that of the standard element over the full range of frequencies tested. Thus, the flexible foams in the erectable elements had no detrimental effects on the electrical performance of the elements.

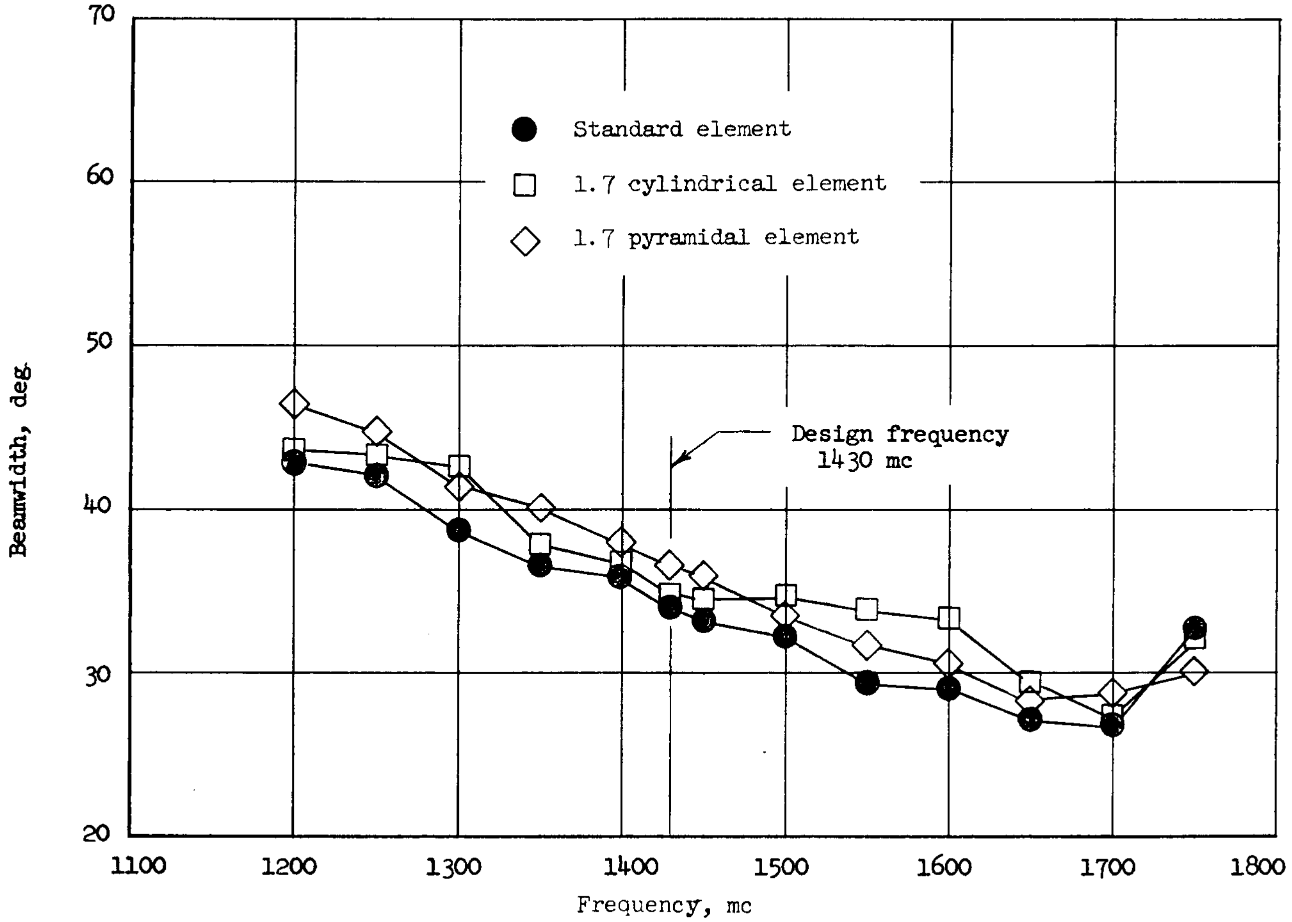


Figure 10.- Comparison of performance characteristics of the erectable elements with those of a standard element. (See ref. 1.)

CONCLUSIONS

The concept of using flexible foam for the erecting mechanism and supporting structure of erectable Yagi disk entenna elements for use in a space environment has been investigated and the results indicate that:

1. There were no significant detrimental effects of the simulated space environment on the recovery properties and resilience of the flexible foams.

2. The packaging, erection, damping, and temperature differential properties of the erectable elements were acceptable within the tolerances necessary for normal antenna performance.

3. The electrical performance characteristics of the undisturbed erectable elements were essentially the same as those of a standard element.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., November 21, 1962.

REFERENCE

1. Croswell, William F., and Gilreath, Melvin C.: Erectable Yagi Disk Antennas for Space Vehicle Applications. NASA TN D-1401, 1962.

NASA-Langley, 1963 L-1993